Multifunctional Structures and Materials: the Ultimate Biomimicry

UDRI
UNIVERSITY of DAYTON RESEARCH INSTITUTE

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Dr. Paul Kladitis
Leader, Multifunctional Products Group

Multi-Scale Composites & Polymers Division
University of Dayton Research Institute
paul.kladitis@udri.udayton.edu

Overview

- Multifunctional structures and materials
- The more conspicuous examples of biomimicry are superficial
- Multifunctionality is a significant fundamental trait of the bio-realm
  - Examples
- Multifunctional structures are the ultimate biomimicry
  - Not so popular – why?
- Application Example
  - Conductive Plastic & Additive Manufacturing

Definition

- Multifunctionality
  - Imparting one or more necessary system functions to components of a system that are typically only passive mechanical structures
    - Without negatively impacting strength and weight properties
  - Eliminates the need for discrete components required to perform the same function
  - Results in minimized system SWaP and design/manufacturing complexity, and opportunity for additional payload (function)
- Multifunctional Structures
  - A physical structure with multifunctionality
- Multifunctional Materials
  - A material can either be viewed as a structure itself or a component which enables multifunctionality in structures

Multifunctional Structures and Materials

Mechanical Suitability at Minimum Weight +

High electrical conductivity
Low loss
High power handling
• signal, RF, power

RF/EO Management
• high energy protection
• energetic enhancement
• hulls, survivability, other

Fatigue resistance
Cold welding resistance
• gimbal wiring, small radii bends, structures

High thermal radiation
Low heat capacity
• radiators

Customizable thermal conductivity
• thermal straps
• insulation

Low reflectivity
• stray light management

Mechanical damping
High stiffness
• enclosures, structures, bays, boxes, isolation

High Ops Temperature
• structures, engines

Energy Storage/Generation
• structural batteries/capacitors
• power scavenging

Integrated Electronics
• smart structures
• antennae
• heaters

E^3 management
Radiation hardness
• enclosures, hulls
• RF cables

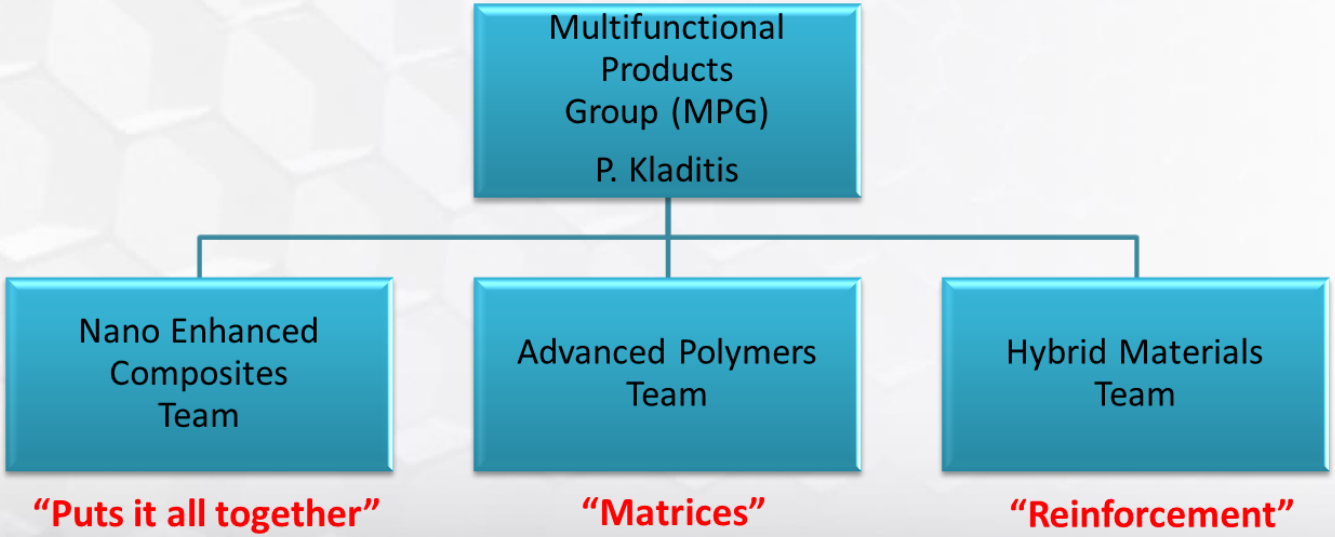
Low thermal expansion
• antennas, optics, structures

Impact resistance
Self-Healing
• weapons
• space debris
• construction handling

= Disruptive Technology
= Reduced size, weight, power, design/manufacturing complexity

Multifunctional Products Group

- Mission
  - Enabling new applications through developing and integrating new and conventional materials into multifunctional composites and materials for reducing size, weight, energy consumption, and manufacturing complexity; and increasing performance, ruggedness, and survivability

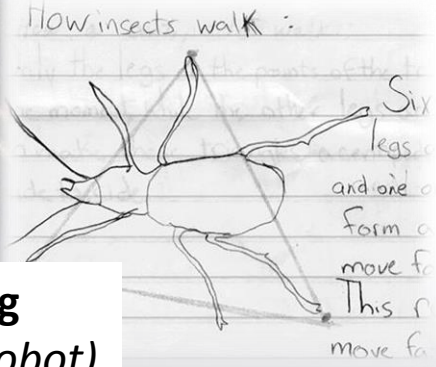


The “Veneer” of Biomimicry

Flies Like a Bird
(UMD/ARL Robo Raven)

Walk Like a Mule
(BD/DARPA-ARL BigDog)

Swims Like a Fish
(USN GhostSwimmer)



Move Like a Bug
(Kladitis Microrobot)

Multifunctionality Underneath the Veneer

- In order for a system to:
  - Fly like a bird
  - Walk like a mule
  - Swim like a fish
  - Move like a bug

Posses
self-sustaining
autonomy

- Multifunctional structures and materials must <u>pervade</u> the system

  …. possibly with no exceptions

Examples of Multifunctional Structures in Nature

With Multifunctionality

Without Multifunctionality

Examples of Multifunctional Structures in Nature

- The Human Body
  - Bones
    - Scaffolding/Frame
    - Impact shielding
    - Chemical synthesis (blood cell production…)
    - Chemical storage
    - Self repair
    - Information transfer

- R. Dulbecco, *Encyclopedia of Human Biology,* 2nd ed. La Jolla, CA: Academic Press, 1997.

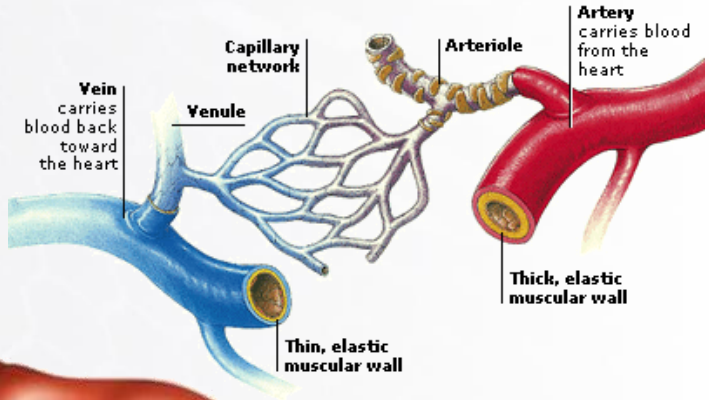
Examples of Multifunctional Structures in Nature

- The Human Body
  - Muscles
    - Mechanical actuation (many purposes)
    - Mechanical stabilization
    - Cushion
    - Heat generation
    - Chemical processing
    - Aesthetics
    - Self repair
    - Information transfer

- R. Dulbecco, *Encyclopedia of Human Biology,* 2nd ed. La Jolla, CA: Academic Press, 1997.
- C. van der Poel, P. Levinger, B.A. Tonkin, I. Levinger, and N.C. Walsh, "Impaired muscle function in a mouse surgical model of post-traumatic Osteoarthritis," *Osteoarthritis and Cartilage,* Vol. 24, No. 6, pp. 1047–1053, June 2016.

Examples of Multifunctional Structures in Nature

- The Human Body
  - Arteries and Veins
    - Hydraulic containment
    - Active flow control
    - Self repair
    - Information transfer
  - Organs: Liver
    - Chemical production
    - Chemical storage
    - Chemical synthesis
    - Self repair
    - Information transfer



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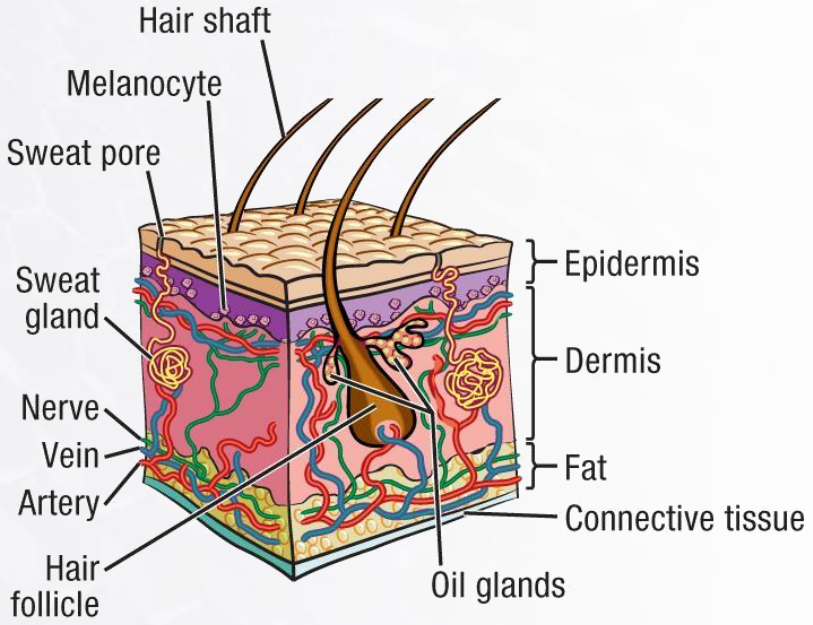
Examples of Multifunctional Structures in Nature

- The Human Body
  - Skin
    - Mechanical cover
    - Radiation shielding
    - Chemical-Bio shielding
    - Filter
    - Chemical synthesis
    - Thermal management
    - Aesthetics
    - Self repair
    - Information transfer



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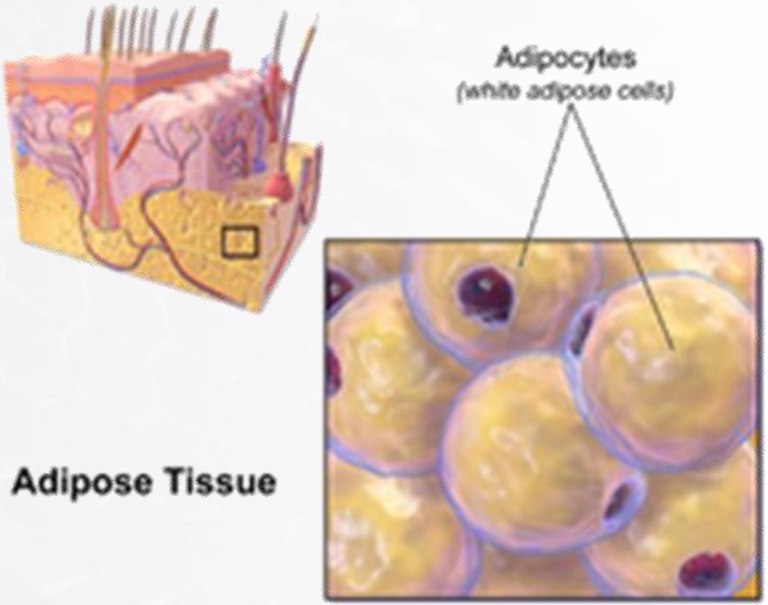
Examples of Multifunctional Structures in Nature

- The Human Body
  - Fat
    - Mechanical cushion
    - Thermal insulation & shielding
    - Energy storage
    - Nutrient storage
    - Aesthetics
    - Chemical production
    - Information transfer



- R. Dulbecco, *Encyclopedia of Human Biology,* 2nd ed. La Jolla, CA: Academic Press, 1997.
- K.J. Suchacki, W.P. Cawthorn, and C.J. Rosen, "Bone Marrow Adipose Tissue: Formation, Function, and Regulation," *Musculoskeletal, Current Opinion in Pharmacology,* Vol. 28, pp. 50-56, June 2016.

Multifunctional Structures in Nature

So ….

- Nature has the most optimum system designs
- HIGHLY Multifunctional Structures and Materials proliferate these natural systems
- Multifunctional Structures enable the conspicuous traits we admire and mimic
- Enabling Multifunction Material to “mimic” may be Carbon

Therefore ….

- To go even further in the area of biomimicry, we should make development of multifunctional structures and materials TOP PRIORITY

Challenges to Multifunctionality

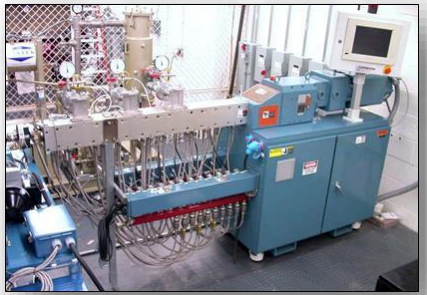
- Design$_{(verb)}$ Complexity
  - More difficult to think about – engineers are lazy
- Maintainability Requirements
  - Maintenance nightmare – until self-healing is realized
- Manufacturability
  - Manufacturing infrastructure not yet suited for this – based on singular/serial components/functions
- Short Term Gain
  - Not as sexy as the veneer functions
  - Needs more development
- Cost
  - Development, Maintenance, Industrial Capital, etc.

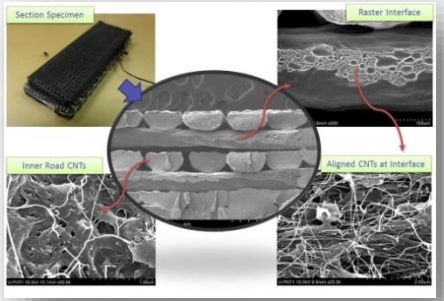
Multifunctional FDM

- What multifunctionality should be pursued first with most potential for impact?
  - Integrated electronics
- What parallel bottoms-up manufacturing technique would be most amenable to make a highly integrated multifunctional structure?
  - Additive Manufacturing

Conductive Thermoplastic + Fused Deposition Modelling (FDM)

Multifunctional FDM





Base Thermoplastic

Polymer Chemistry/Synthesis

Nano-Fillers → Treatments

Small Batch Compounding (100s g) → Screening Panel & Specimen Fabrication → Material Property Measurement → Compound Downselect

Large Batch Compounding (~50 lbs) → Filament Extrusion → Pelletized Filament

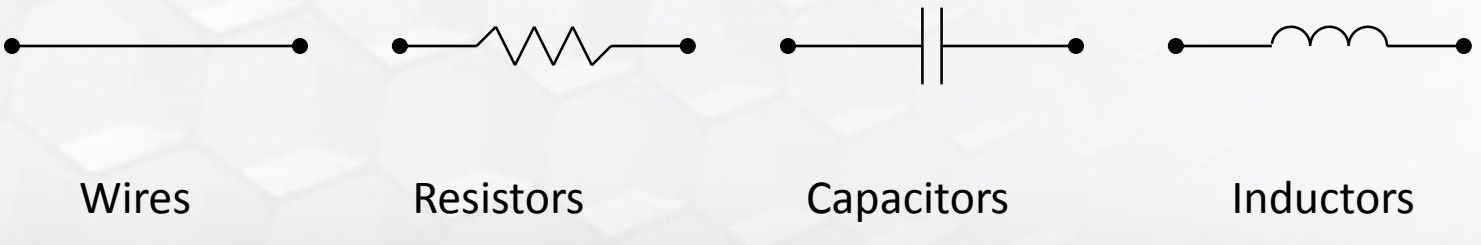
Ship to Stratasys

0.071" Filament Returned from Stratasys → Printing Parameter Optimization → Printed Parts → Material Property Confirmation → Printing Problems?

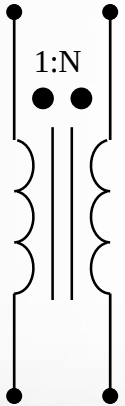
Material & Process Refinement

Multifunctional FDM

- New thermoplastics enable multifunctional FDM structures
- World's first FDM printed wire connectors, CNT wires, wire harnesses, and other structures
  - Space qualified and flying now
- Two material printing of Conductive & Nonconductive Thermoplastics (conductor & insulator)
  - Enables all passive electrical circuit elements
  - Enables functions only requiring passive elements



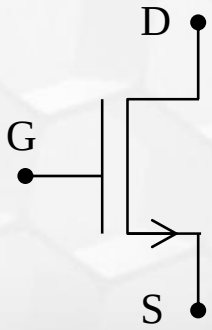
Wires Resistors Capacitors Inductors



Transformers

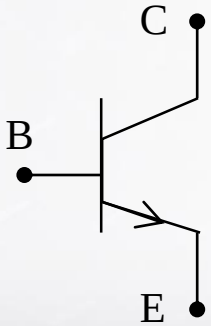
Multifunctional FDM

- Passive elements are not enough for full electrical function – What is still missing are
  - p-n junction: enables diode, varactor, and transistors
    - rectification, variable capacitor, amplification, switching
  - battery: enables power supply



MOSFET

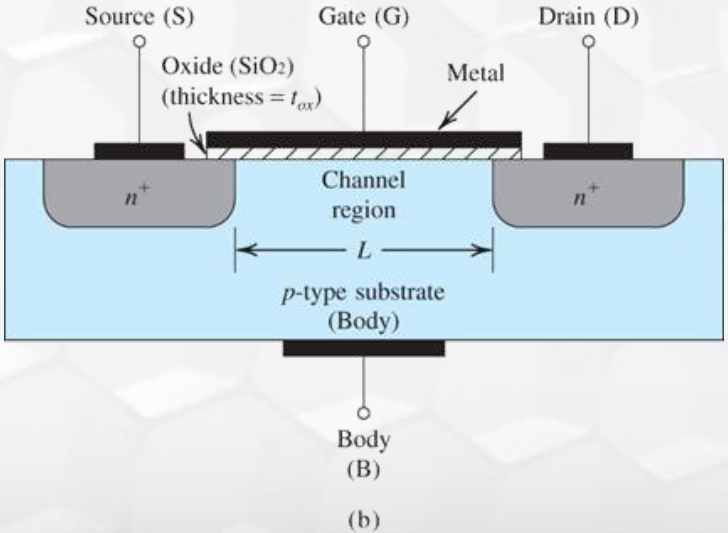
Diode
&
Varactor
(p-n junction)



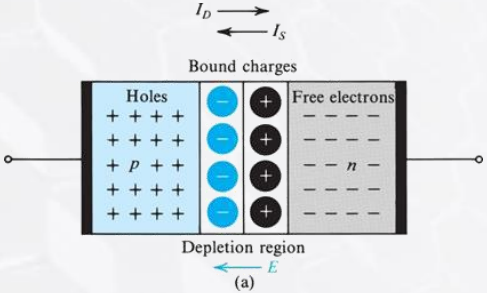
BJT

Multifunctional FDM

- p-n junction is the heart of transistor action



MOSFET



Diode
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Varactor
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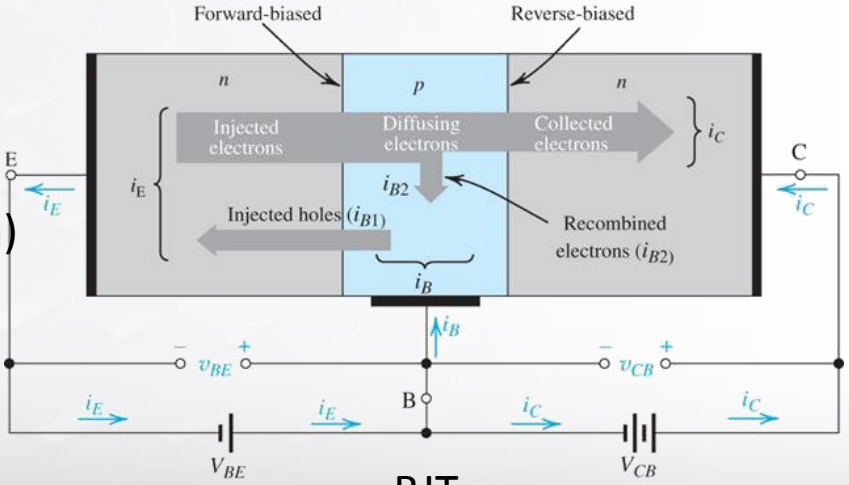

BJT

Summary

- Multifunctional structures and materials
- The more conspicuous examples of biomimicry are superficial
- Multifunctionality is a significant fundamental trait of the bio-realm
- Multifunctional structures are the ultimate biomimicry
  - Should be top priority
- Challenges
- Integrated Electronics
  - Conductive Plastic & Additive Manufacturing

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